MICROWAVE ANTENNA RADIATION HAZARDS ANALYSIS

SEAVEY ENGINEERING ASSOCIATES, INC.

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INTRODUCTION

The accompanying programs calculate microwave radiation power density in milliwatts per square centimeter for several locations around a typical microwave antenna.

Power density is calculated on axis using the formulas of FCC Office of Science and Technology Report OST 65, "Evaluating Compliance with FCC-Specified Guidelines for Human Exposure to Radiofrequency Radiation", dated October, 1985. Excerpts from that report are reprinted below.

Three axial locations are treated: nearfield, transition region and start of far field. Power density at the rim of the reflector is calculated from a specification of the antenna feed characteristics.

At the center of the reflector, power density is calculated in from of the reflecting surface and at the rear. The transmission loss through the surface is considered, which permits analysis of mesh of slatted reflectors. Density at the rim and one diameter out from the reflector is also calculated, assuming a 20 dB falloff from the central axis.

Four separate analysis programs are included:

HAZPRI.BAS	Prime focus circular apertures
HAZCAS.BAS	Symmetrical Cassegrains
HAZSET.BAS	Offset with circular projected apertures
HAZSAT.BAS	Comtech 'OFFSAT' 8 by 18-foot antenna

All analyses are written in GWBASIC, which is included on this diskette. To run the graphics portion of this software, a color graphics adaptor card is also necessary.

The ANSI report titled "American National Standard Safety Levels Human Exposure to RF Electromagnetic Fields" establishes safe limits on radiation. Excerpts from that report are reprinted below. For whole-body protection, the limit is 5 milliwatts/square centimeter taken over a 6 minute period, for frequencies in the 1.5-100 GHz frequency range. This ANSI limit is noted in the four analyses listed above. In general, for Earth Station transmitting antennas, the 5 mw/sq. cm. limit is exceeded on axis. However, this occurs at large distances from the antenna and normally at large heights which are unlikely to cause a problem.

APERTURE ANTENNAS

(Reprinted from Section II of FCC Office of Science and Technology Report OST 65, "Evaluating Compliance with FCC-Specified Guidelines for Human Exposure to Radiofrequency Radiation". NOTE: Some of the variables in the equations quoted below have been renamed to facilitate printing from an ASCII format file.)

Aperture antennas include those used for such applications as satellite earth stations, point-to-point microwave radio, radio astronomy, and various types of radar. Generally these types of antennas have parabolic surfaces and many have circular cross sections. They are characterized by their high gain which results in the transmission of power in a well-defined collimated beam with little angular divergence. Systems using aperture antennas operate at microwave frequencies, i.e., generally above 1 GHz.

Those systems involved in telecommunications operate with power levels that depend on the distances over which communications are to be transmitted and the number of channels required. All have circular cross sections, and antenna diameter is an important characteristic that is generally determined by the requirements for reception. With regard to some operations, such as satellite-earth transmitting antennas, the combination of high transmitter power and large antenna diameters produce regions of significant power density that may extend over relatively large distances in the main beam. Many dish antennas used for satellite-earth transmissions utilize the Cassegrain design in which power is fed to the antenna from a primary source located at the center of the parabolic reflector. Radiation from this source is then incident on a small hyperbolic subreflector located between the power feed and the focal point of the antenna and is then reflected back to the main reflector resulting in the transmission of a collimated beam.

Because of the highly directional nature of these and other aperture antennas, the possibility of significant human exposure to RF radiation is considerably reduced. The power densities existing at locations where people may be exposed would be substantially less than on-axis power densities. Factors that would have to be taken into account in assessing the potential for exposure would be main-beam orientation, antenna height above ground, location relative to where people live or work, and the operational procedures followed at the facility.

Satellite-earth uplink stations have been studied analytically and by measurement to determine methods to estimate potential environmental exposure levels. An empirical model has been developed, based on antenna theory and measurements, to evaluate potential environmental exposure from these systems (Reference 4).

In general, for parabolic aperture antennas with circular cross sections, the following information can be used in evaluating a specific system for potential environmental exposure (for a more complete discussion of this topic see Reference 4). In the near-field, or Fresnel region, of the main beam, the power density can be at a maximum before it begins to decrease with distance. The extent of the near-field can be described by the equation:

$$R = \frac{D^2}{4\ WL} \qquad (1)$$

where: R = extent of near-field
D = antenna diameter
WL = wavelength

The magnitude of the on-axis (main beam) power density varies according to location in the near-field. However, the maximum value of the near-field on-axis power density is given by the equation:

$$S = \frac{16EP}{cD^2} \qquad (2)$$

where: S = maximum near-field power density
E = aperture efficiency, typically 0.5-0.75
P = power fed to the antenna
D = antenna diameter

Power density in the transition region decreases inversely with distance from the antenna, while power density in the far-field (Fraunhofer region) decreases inversely as the square of the distance. For purposes of evaluating potential exposure, the distance to the beginning of the far-field region can be expressed by the equation:

$$R = \frac{0.6D^2}{WL} \qquad (3)$$

where: R = distance to beginning of far-field
D = antenna diameter
WL = wavelength

On-axis power densities in the transition region and in the far-field of an aperture antenna can be estimated by use of the following equations:

Transition Region:

$$S = \frac{(SNF)(RNF)}{R} \qquad (4)$$

where: S = power density
SNF = maximum power density for near-field calculated using (2) above
RNF = extent of near-field calculated using (1) above
R = distance to point of interest

Far-Field:

$$S = \frac{PG}{4\ cR^2} \qquad (5)$$

where: S = power density (on axis)
P = power fed to the antenna
G = gain of the antenna relative to isotropic
R = distance to the point of interest

In the far-field region, power is distributed in a series of maxima and minima as a function of the off-axis angle (defined by the antenna axis, the center of the antenna, and the specific point of interest). For constant phase or uniform illumination, over the aperture the main beam will be the location of the greatest of these maxima. The on-axis power densities calculated from the above formulas represent the maximum exposure levels that the system can produce. Off-axis power densities will be considerably less. Estimated exposure levels have been calculated for many satellite communications system operating at normal transmitting powers. A comparison of measured and predicted values is given in Reference 5.

For off-axis calculations in the near-field and in the transition region it can be assumed that, if the point of interest is at least one antenna diameter removed from the center of the main beam, the power density at that point would be at least a factor of 100 (20 dB) less than the value calculated for the equivalent distance in the main beam (see Reference 4 for data). For off-axis calculations in the far-field, the calculated main power density obtained by the use of equation (5) above can be multiplied by the appropriate relative power density factor obtained from the antenna gain pattern to obtain a more realistic estimate.

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NOTE: The following is reprinted from relevant sections of the "American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz" (ANSI C95.1-1982).

AMERICAN NATIONAL STANDARD SAFETY LEVELS WITH RESPECT TO HUMAN EXPOSURE TO RADIO FREQUENCY ELECTROMAGNETIC FIELDS 300 kHz TO 100 GHz

1. SCOPE AND PURPOSE

Recommendations are made to prevent possible harmful effects in human beings exposed to electromagnetic fields in the frequency range from 300 kHz to 100 GHz. These recommendations are intended to apply to non-occupational as well as to occupational exposures. These recommendations are not intended to apply to the purposeful exposure of patients by or under the direction of practitioners of the healing arts.

2. DEFINITIONS

RADIO FREQUENCY PROTECTION GUIDES (RFPG).
The radio frequency field strengths or equivalent plane wave power densities which should not be exceeded without (1) careful consideration of the reasons for doing so, (2) careful estimat[illegible] the increased energy deposition in the human body, and (3) car[illegible] consideration of the increased risk of unwanted biological ef[illegible]

SPECIFIC ABSORPTION RATE (SAR).
The time rate at which radio-frequency electromagnetic energy is imparted to an element of mass of a biological body.

3. REFERENCES (not reprinted here; see original)

4. RECOMMENDATIONS

4.1 RADIO FREQUENCY PROTECTION GUIDES

For human exposure to electromagnetic energy at radio frequencies from 300 kHz to 100 GHz, the protection guides, in terms of the mean squared electric and magnetic field strengths and in terms of the equivalent plane-wave free-space power density, as a function of frequency, are given in Table 1.

For near field exposures, the only applicable protection guides are the mean squared electric and magnetic field strengths as given in Table 1, columns 2 and 3. For convenience, these guides may be expressed as the equivalent plane wave power density, given in Table 1, column 4.

For mixed or broadband fields at a number of frequencies for which there are different values of protection guides, the fraction of the radio frequency protection guide incurred within each frequency interval should be determined, and the sum of all such fractions should not exceed unity.

TABLE I

RADIO FREQUENCY PROTECTION GUIDES

1	2	3	4
Frequency Range (MHz)	Electric Field Strength E^2 (V^2/m^2)	Magnetic Field Strength H^2 (A^2/m^2)	Power Density (mW/cm^2)
0.3-3	400,000	2.5	100
3-30	$4,000(900/f^2)$	$0.025(900/f^2)$	$900/f^2$
30-300	4,000	0.025	1.0
300-1500	4,000(f/300)	0.025(f/300)	f/300
1500-100,000	20,000	0.125	5.0

NOTE: f = frequency in megahertz (MHz)

E^2 = electric field squared

H^2 = magnetic field squared

V^2/m^2 = volts squared per meter squared

A^2/m^2 = amperes squared per meter squared

mW/cm^2 = milliwatts per centimeter squared

4.2 EXCLUSIONS

1) At frequencies between 300 kHz and 100 GHz, the protection guides may be exceeded if the exposure conditions can be shown by laboratory procedures to produce specific absorption rates (SARs) below 0.4 W/kg as averaged over the whole body, and spatial peak SA values below 8 W/kg as averaged over any one gram of tissue.

2) At frequencies between 300 kHz and 1 GHz, the protection guides may be exceeded if the radio frequency input power of the radiating device is seven watts or less.

4.3 MEASUREMENTS

1) For both pulsed and non-pulsed fields, the power density, the squares of the field strengths, and the values of specific absorption rates (SARs) or input power, as applicable, are averaged over any 0.1 h period. The time-averaged values should not exceed the values given in Table 1 or in the Exclusions, 4.2.

2) Measurements to determine adherence to the recommended protection guides shall be made at distances 5 cm or greater from any object [refer to ANSI C95.3-1973, American National Standard Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies and ANSI C95.5-1981, American National Standard Recommended Practice for Measurement of Hazardous Electromagnetic Fields-RF and Microwave.]

5. EXPLANATION

Exposure to electromagnetic fields in the frequency range under consideration is but one of the several sources of energy input into the body, which requires wide ranges of energy production and dissipation in order to function. For situations involving unrestricted exposure of the body, the radio frequency protection guides are believed to result in energy deposition averaged over the entire body mass for any 0.1 h period of about 144 joules per kilogram (J/kg) or less. This is equivalent to a specific absorption rate (SAR) of about 0.40 watts per kilogram (W/kg) or less, as spatially and temporally averaged over the entire body mass.

Biological effects data applicable to humans for all possible combinations of frequency and modulation do not exist. The radio frequency protection guide, therefore, has been based on the best available interpretations of the literature and is intended to eliminate adverse effects on the functioning of the human body.

Exclusion criterion (2) to the protection guides can be used in relation to fields from low power devices such as hand-held, mobile, and marine radio transceivers. These devices may emit localized fields exceeding the protection guides, but will result in a significantly lower rate of energy absorption than allowed for the whole body average. Thus, exposure to fields emitted by devices operating at 1 GHz or lower and at less than 7 W output power would not be restricted. Exposure to fields from devices with greater output power or operating at frequencies above 1 GHz require a case-by-case analysis to determine if exclusion criterion (1) is applicable.

Because of the limitations of the biological effects data base, these guides are offered as upper limits of exposure, particularly for the population at large. Where exposure conditions are not precisely known or controlled exposure reduction should be accomplished by reliable means to values as low as are reasonably achievable. Exposures slightly in excess of the radio frequency protection guides are not necessarily harmful, however, such exposures are not desirable and should be prevented wherever possible.

6. RATIONALE

[not reprinted here; see original ANSI document for rationale]

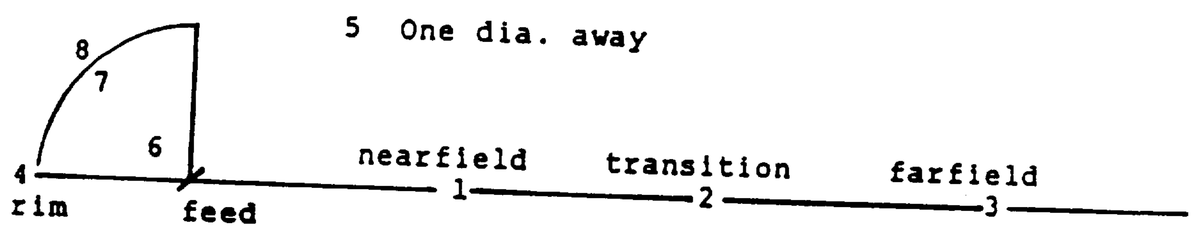
COMTECH OFFSAT ANTENNA DATA

ANTENNA SIZE	8-FOOT BY 18-FOOT COMTECH OFFSAT
REFLECTOR FOCAL LENGTH	75.78 INCHES
FREQUENCY	6 GHz
INPUT POWER	450 WATTS CW
ANTENNA EFFICIENCY	55 %
FEED GAIN IN dBi	16.0
FEED EDGE TAPER	10 dB

POWER DENSITIES IN MW/SQ.CM.

LOCATION - DESCRIPTION	MW/SQ.CM.	AXIAL DISTANCE, FEET
1 - NEARFIELD ON AXIS	8.68	238.35
2 - TRANSITION REGION ON AXIS	3.62	572.03
3 - START OF FARFIELD ON AXIS	0.34	1906.78
4 - REFLECTOR RIM NEAREST FEED BOOM	3.85	
5 - ONE DIAMETER OUT AT RIM RADIUS	0.10	
6 - IN FRONT OF FEED	67.48	
7 - IN CENTER OF REFLECTOR	76.96	
8 - BEHIND CENTER OF REFLECTOR	0.00	

NOTE: ANSI LIMIT IS 5 MW/SQ.CM. FOR 6 MINUTES EXPOSURE



COMTECH OFFSAT ANTENNA VERTICAL PLANE RADIATION HAZARD LOCATIONS

Horizontal line indicates main beam direction